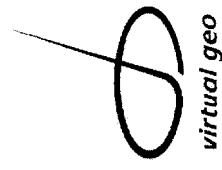


Result:

VGSO Duplicates Slot Availability in GSO!

- ~180 slots using min 2 degrees separation
- ~72 using 5 degrees
- etc



VGSO Sharing Potential

The “Virtual Slot”

- 12 Possible Active Arcs (6 in Northern Hemisphere, 6 in Southern)
- Minimum 2 degrees of separation at apogee between satellites emulating GSO-like slots
- 180 active at any given time

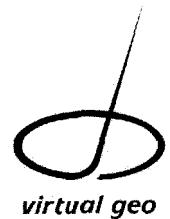
Number of “Systems”

- 30 full global systems or...
- 60 hemispheric systems or...
- 180 regional satellite operators
(2° spacing option)



Selection of Orbit Parameters

- VGSO is *Ground Track* centered, not orbit centered, hence
 - Uses (near) integer mean motion rather than semi-major axis to freeze ground track
 - Uses Longitude of Apogee/Americas (or Longitude of Ascending Node/Americas) rather than Right Ascension of Ascending Node
 - Uses critical inclination: 63.435 degrees
 - preventing rotation of apogee around orbit
 - Uses 270 or 90 degree argument of perigee
 - Keeping apogeess well away from GSO arc
- Uses eccentricity of 0.63
 - Keeping orbit well out of atmosphere, away from most LEOs



Standard Orbital Parameters

Mean Motion	3.004: freeze ground track (including correction for regression of nodes to freeze ground track)
Inclination	63.435° : freeze apogee (to freeze rotation of line of apsides)
Eccentricity	0.63: perigee > 1000 km
Argument of Perigee	270° – Northern arcs 90° – Southern arcs
Longitude of Apogee over Americas	65 or 125° West Longitude defines coverage areas

Defining Tolerances

The Effects of Orbital Inaccuracies

Red is Standard Orbit

Green is inaccurate variation

Ticks are example satellite positions

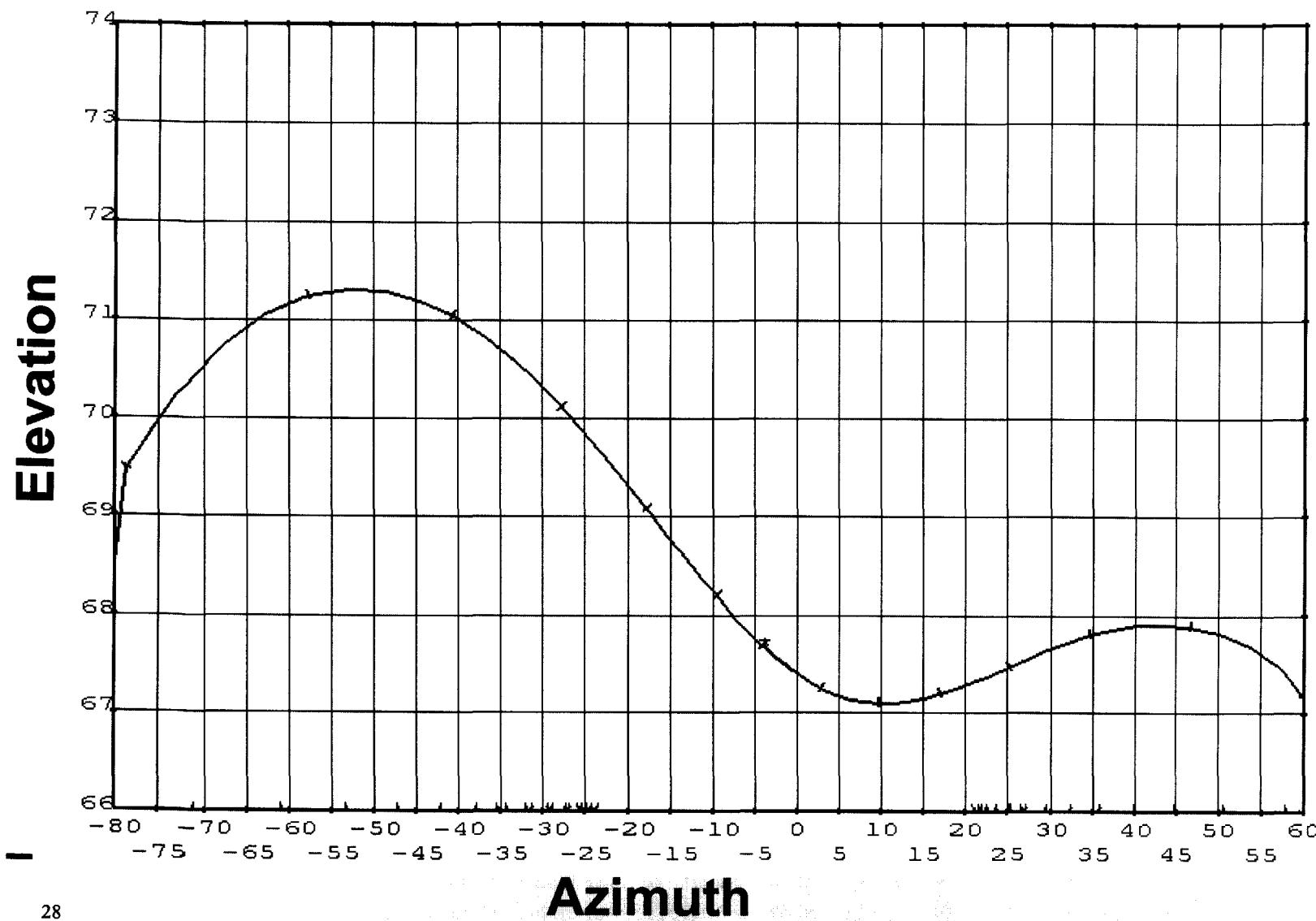
Northern Active Arc seen from arbitrary
location at 45° N

Specification Objectives

- **Easily understood assignment label for general use**
 - Ground Track identity, definition, and
 - Time of Entry
- **Easily understood orbital management for satellite operations**
 - A conventional approach to defining a box
 - In-track, cross-track in active arc
 - How to get those results left to operator
- **Keep it as simple as possible**
 - Assigned numbers relate to ground track when applicable

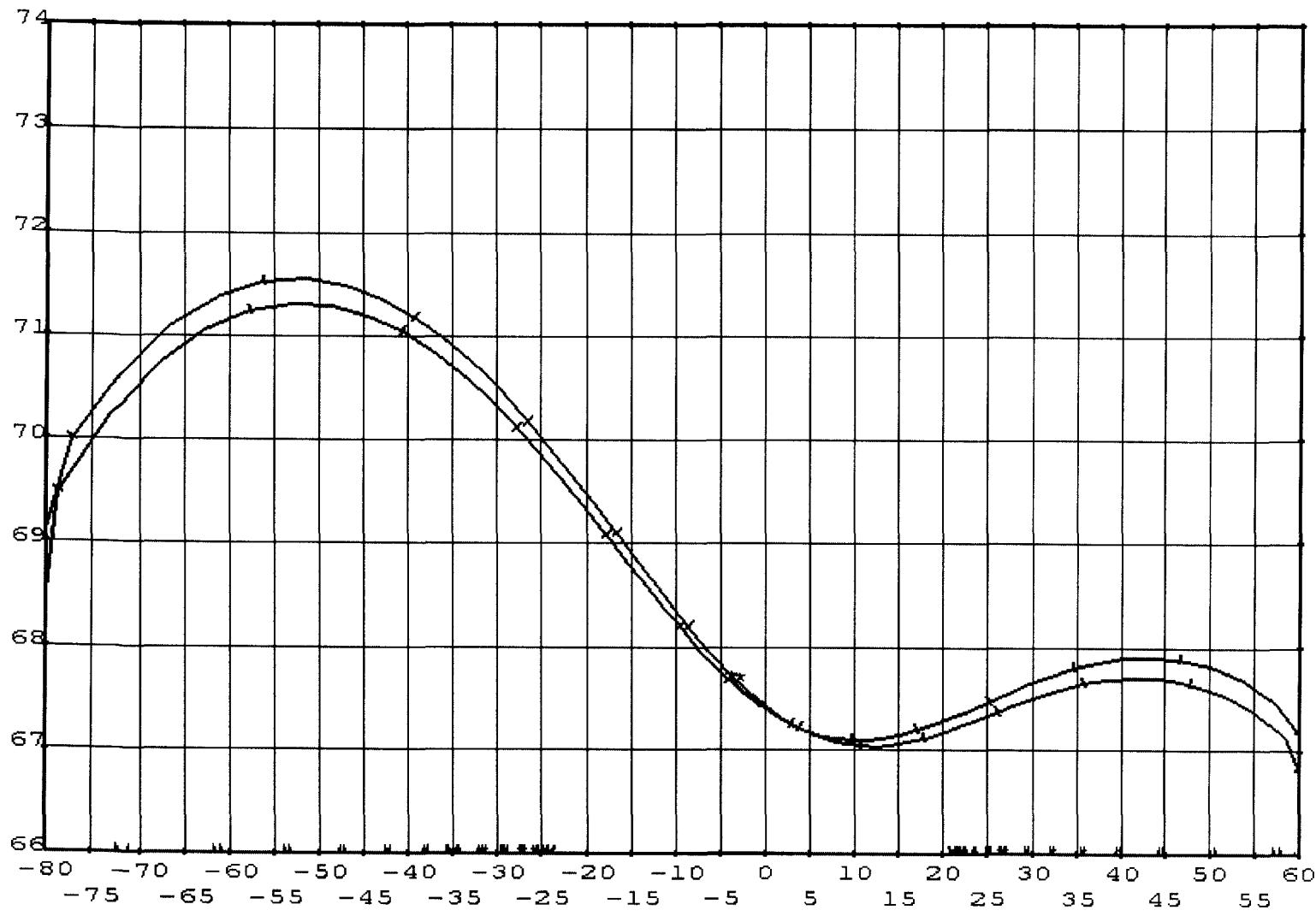
An Active Arc Standard Pass

(Rectangular Plot)

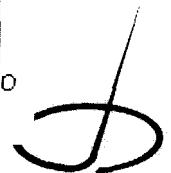
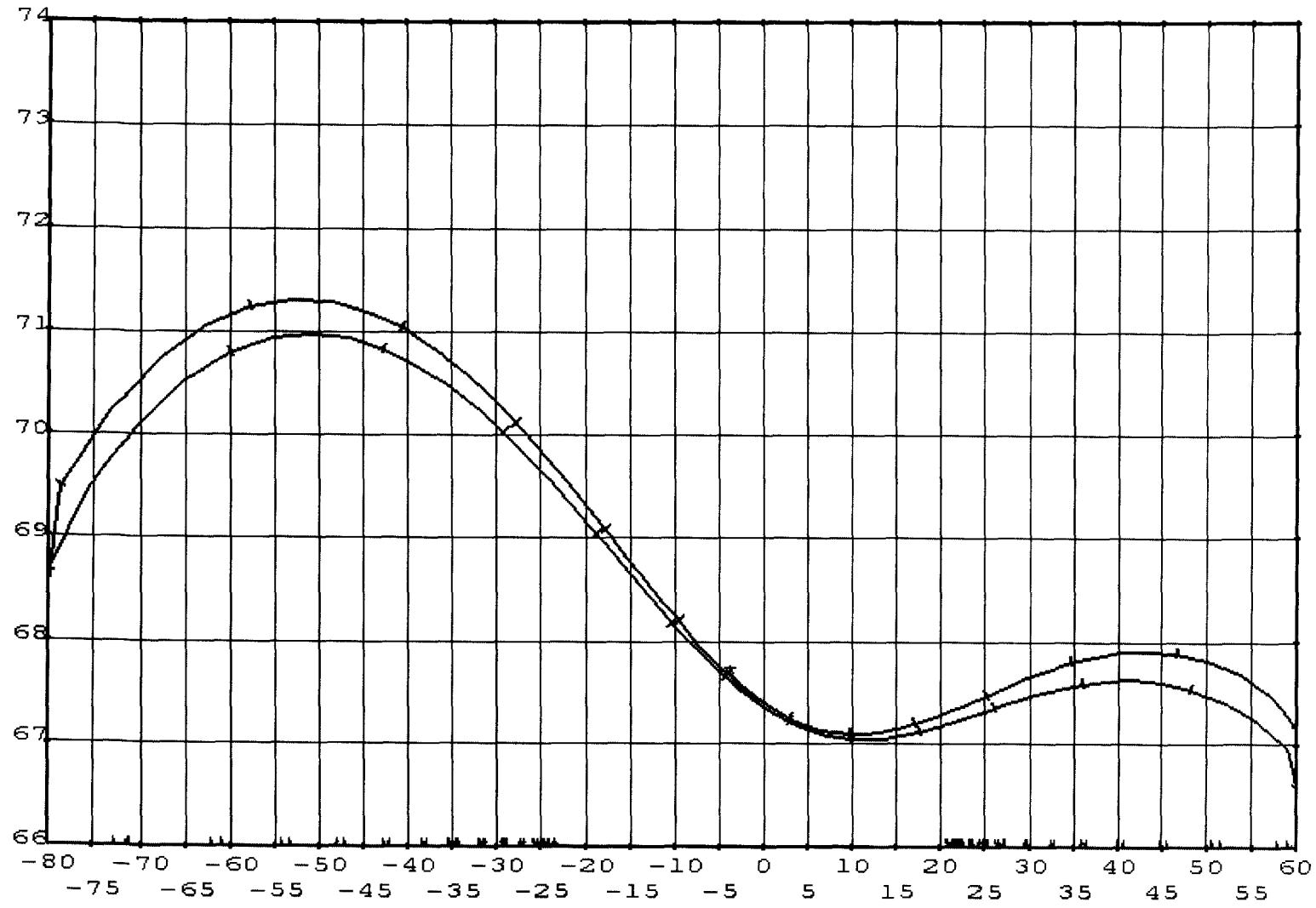


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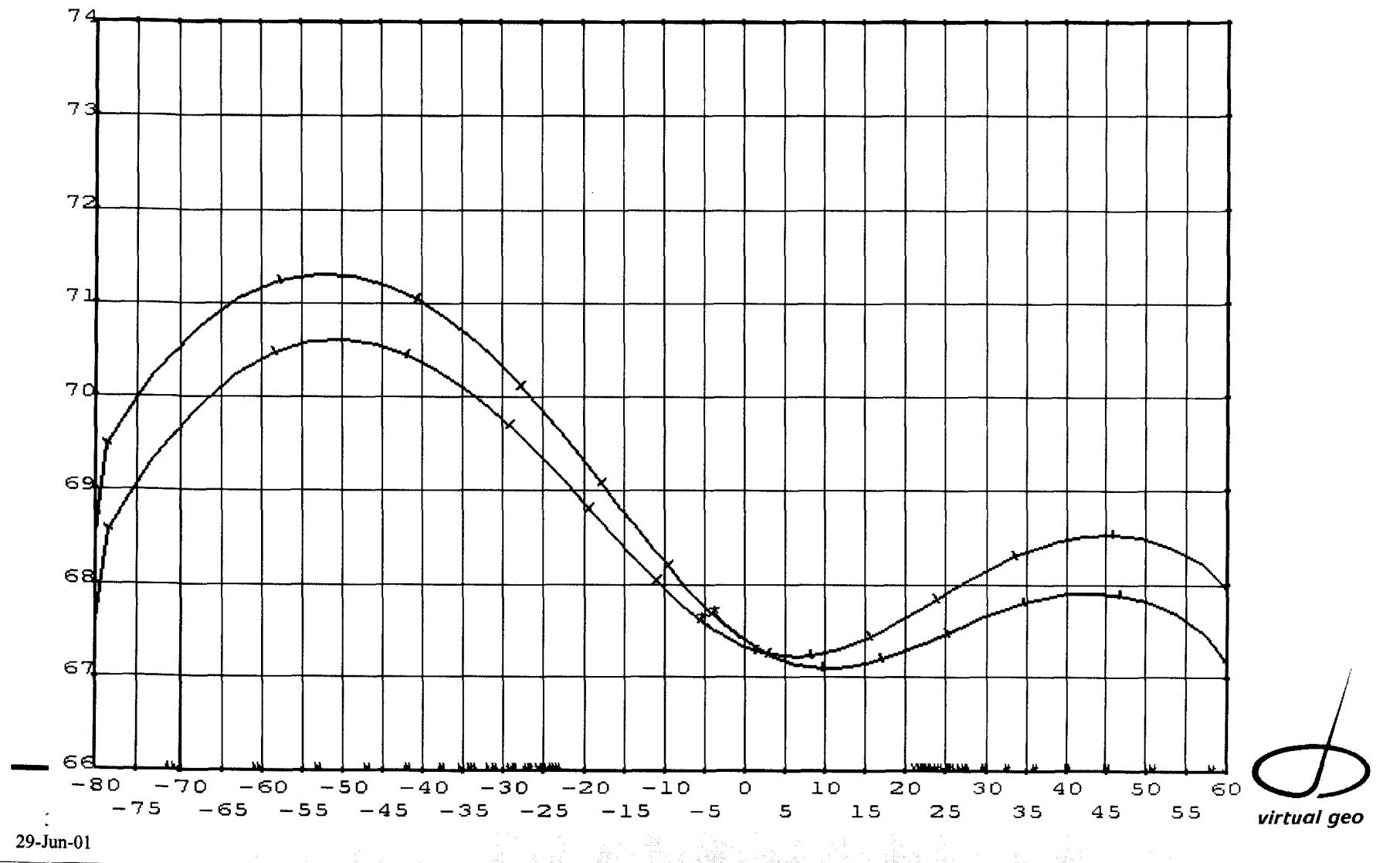
A Pass with Late Mean Anomaly (1°)



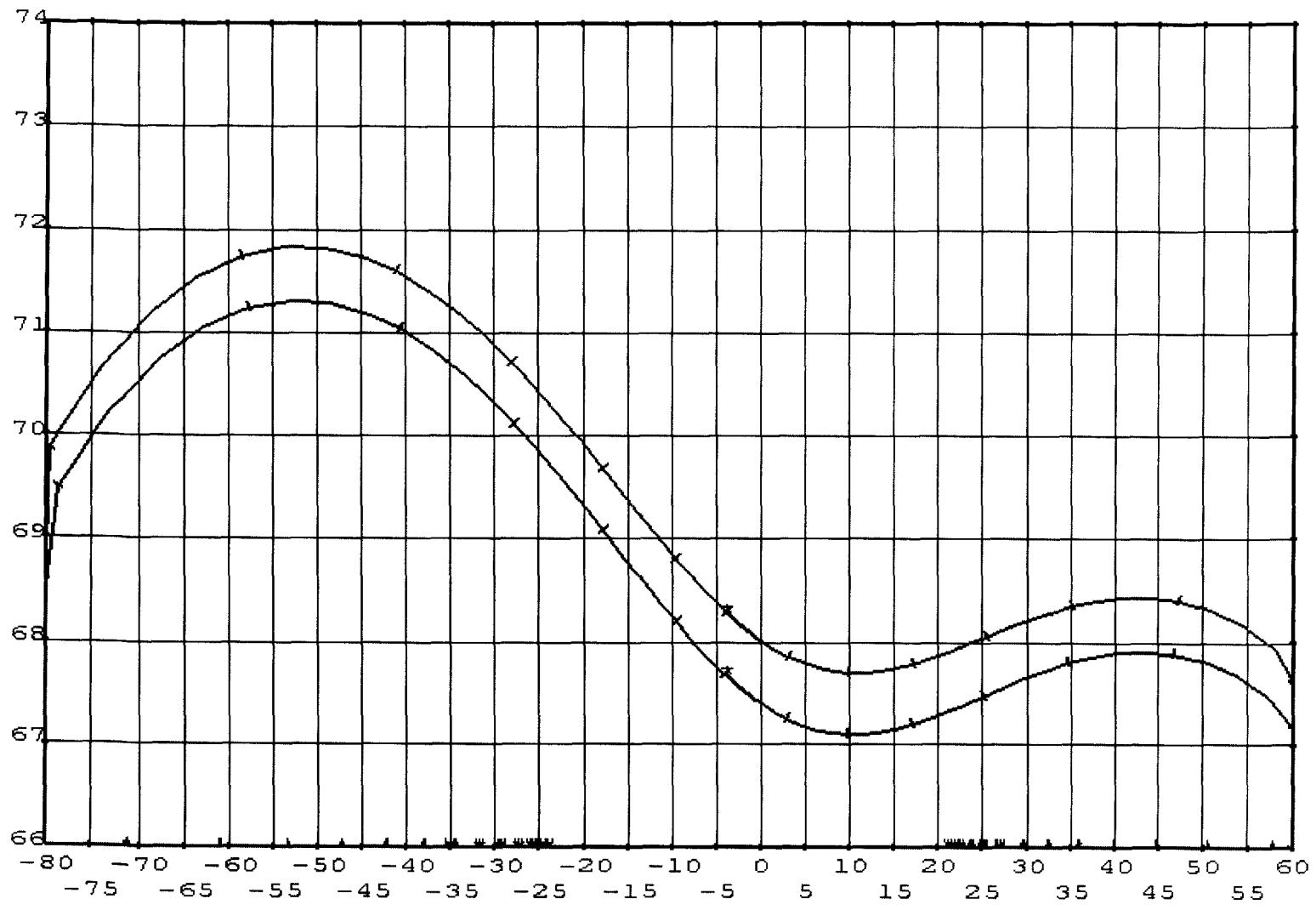
A Less Eccentric Pass (0.62)



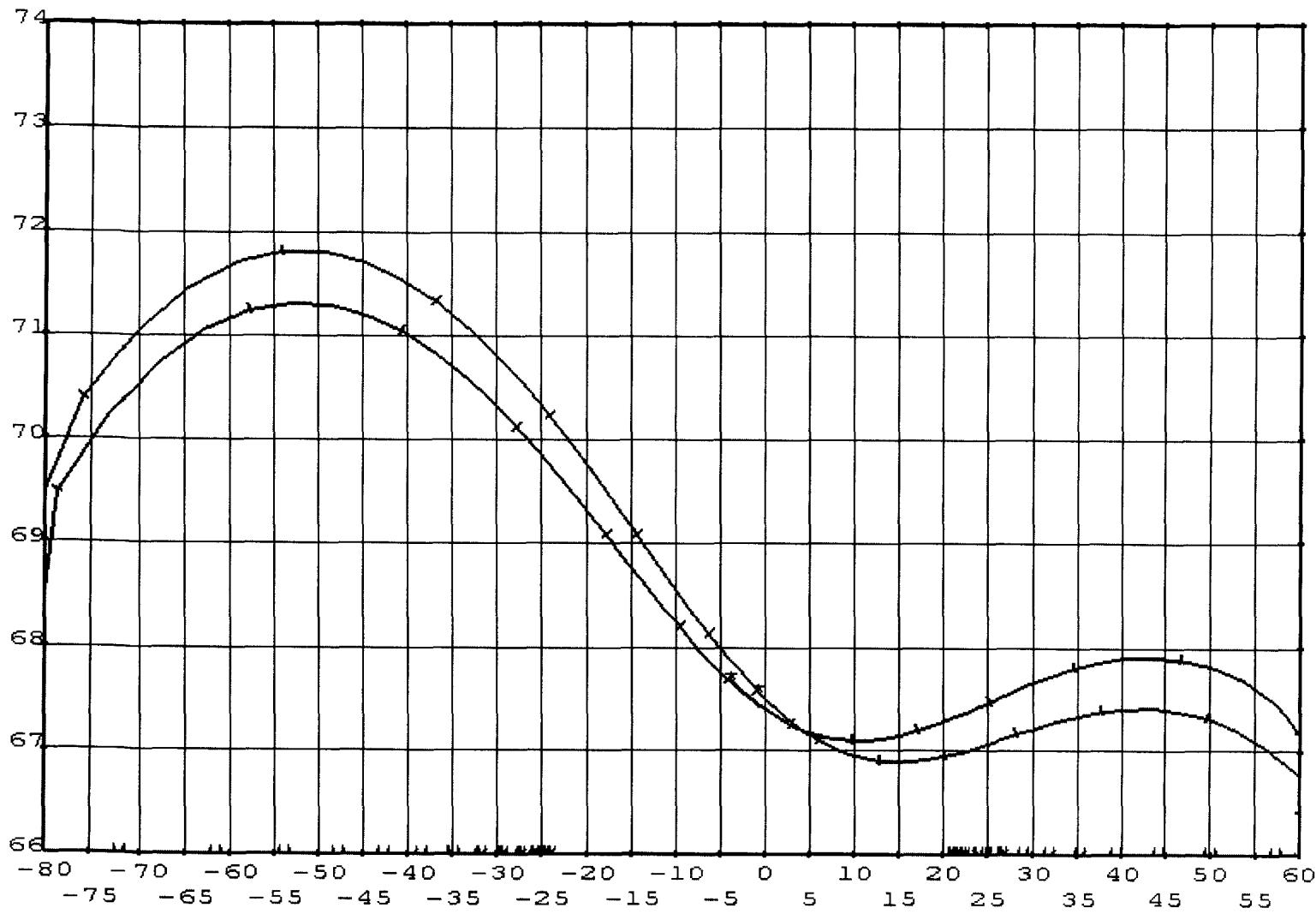
A Pass After Regression of the line of Nodes (1° off)



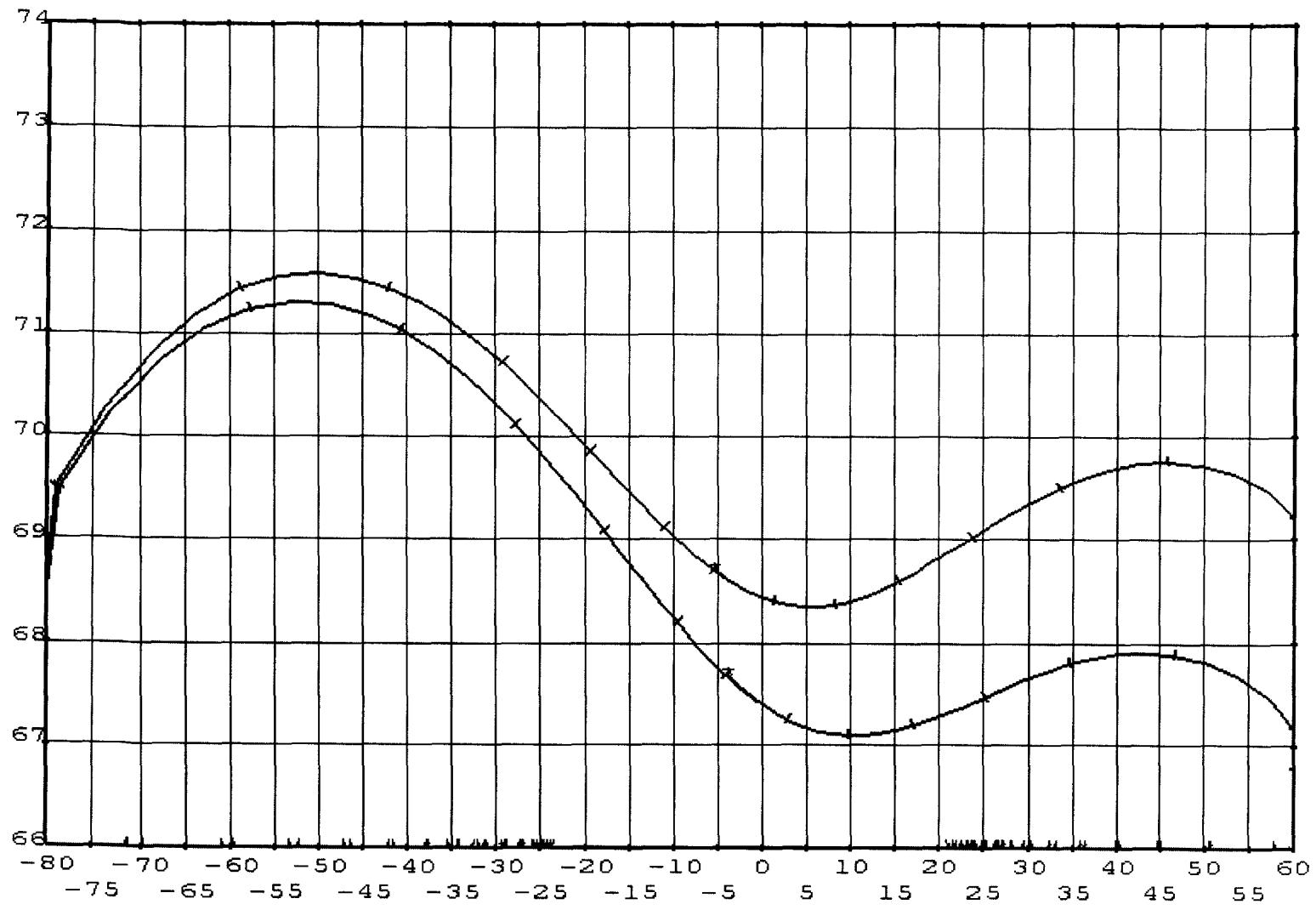
A Pass at Lower Inclination (by 0.5°)



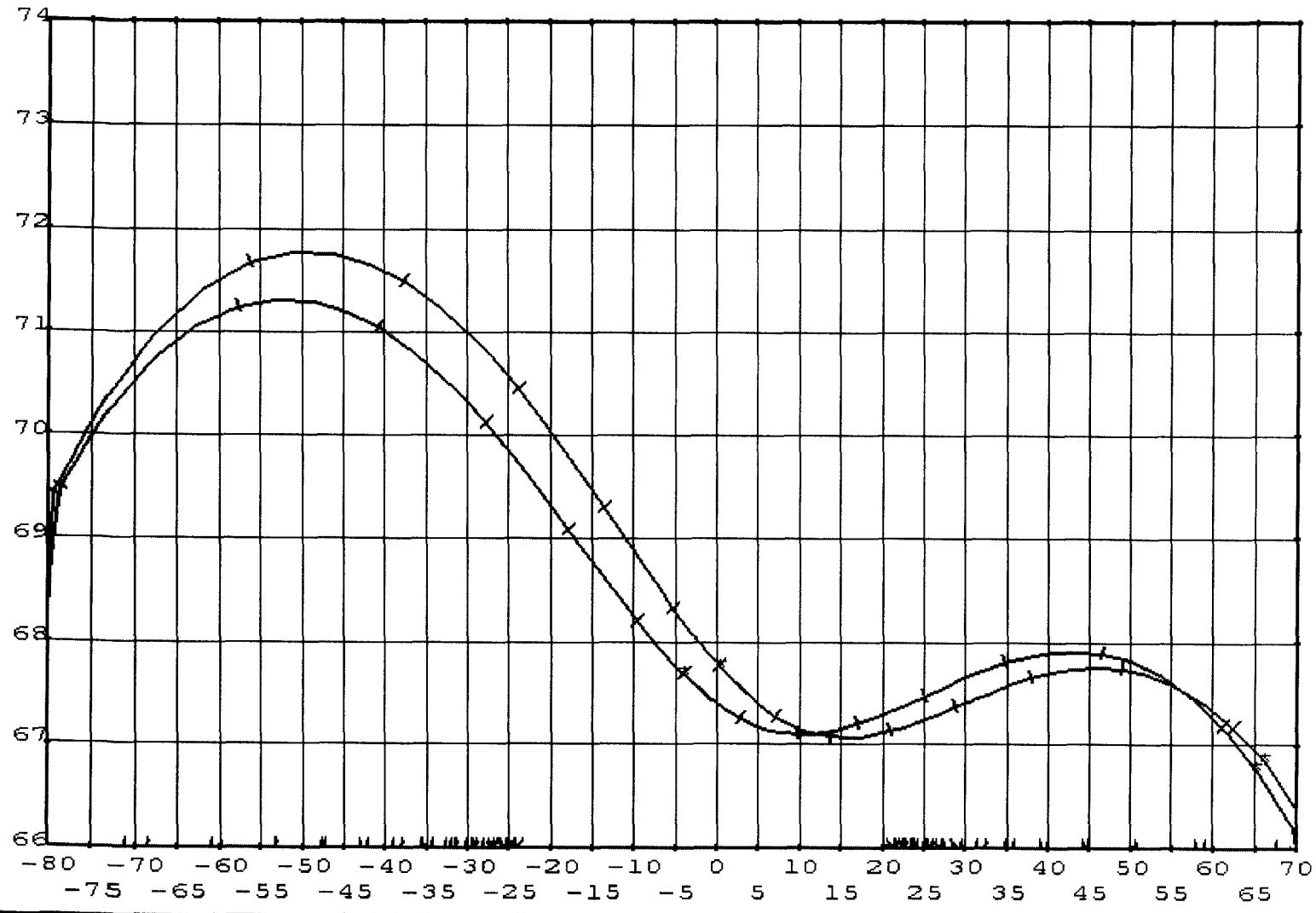
A Shift in Argument of Perigee (by 1°)



Keeping the Entry Point Fixed



Keeping Both Entry and Exit Fixed



The Active Arc Tolerance Solution

✗ Keep Entry, Exit, and Midpoint Fixed?

- Getting Complicated
- Better is . . .

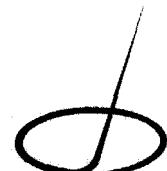
✓ Stay on Track throughout Active Arc.

- Seen from any service area, at any point within Active Arc:
 - In-track: Within 45 seconds of Standard point passage time
 - Cross-Track: Within 0.1 degrees of Standard path

→ Simplest

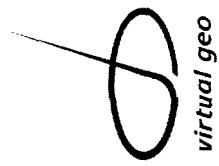
→ Results oriented

 → Stay on track and on time

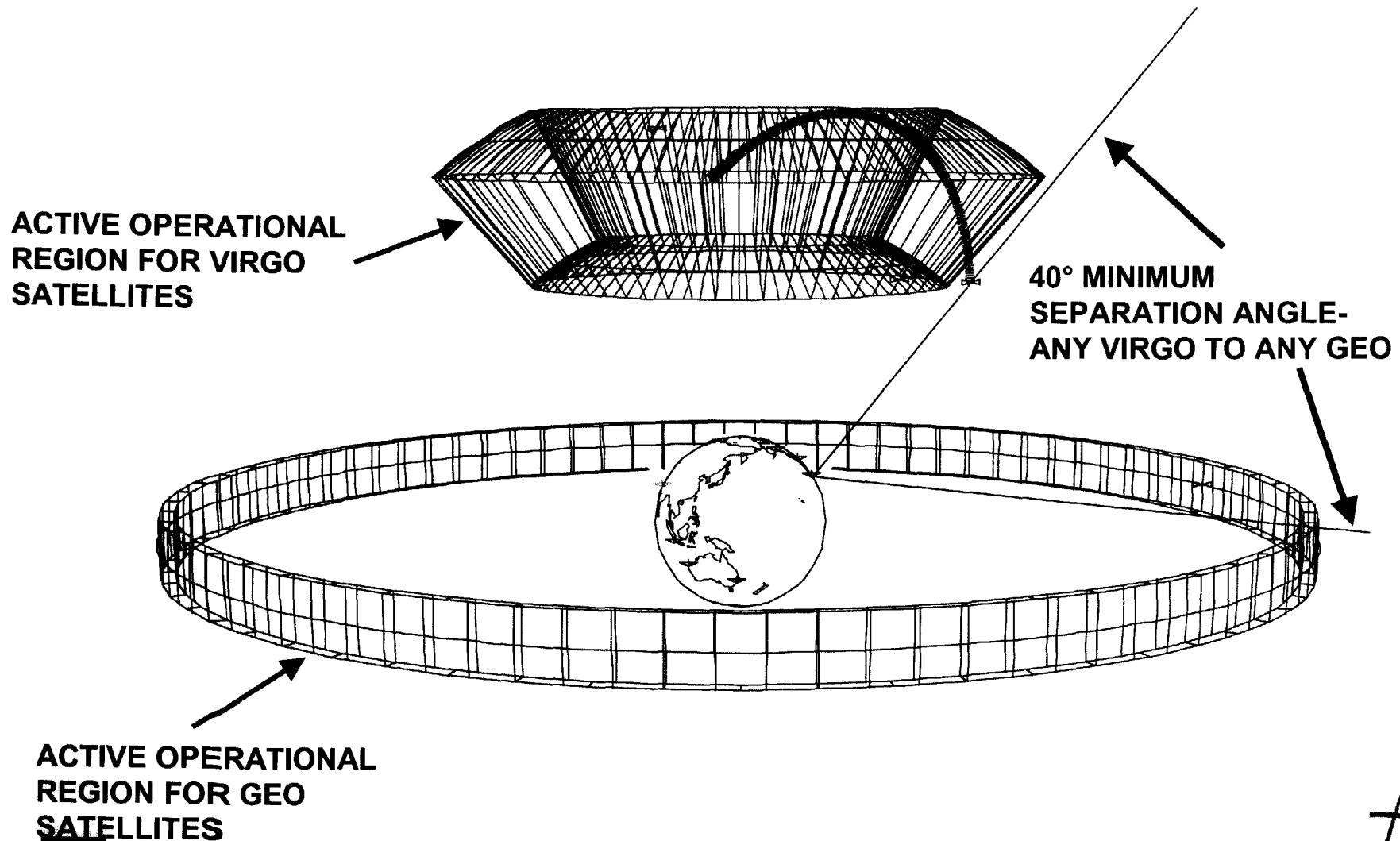


virtual geo

Virtual GEO and Band Sharing



Comparison of Virtual GEO and GSO Operating Regions



Geostationary Arc Separation

- **Actually always more than 45 degrees**
- **Guarantee always more than 40 degrees**
- **Lowest for terminals at far North and far South latitudes**
- **Always >50 degrees in CONUS**

Relative GSO Arc Protection Factors

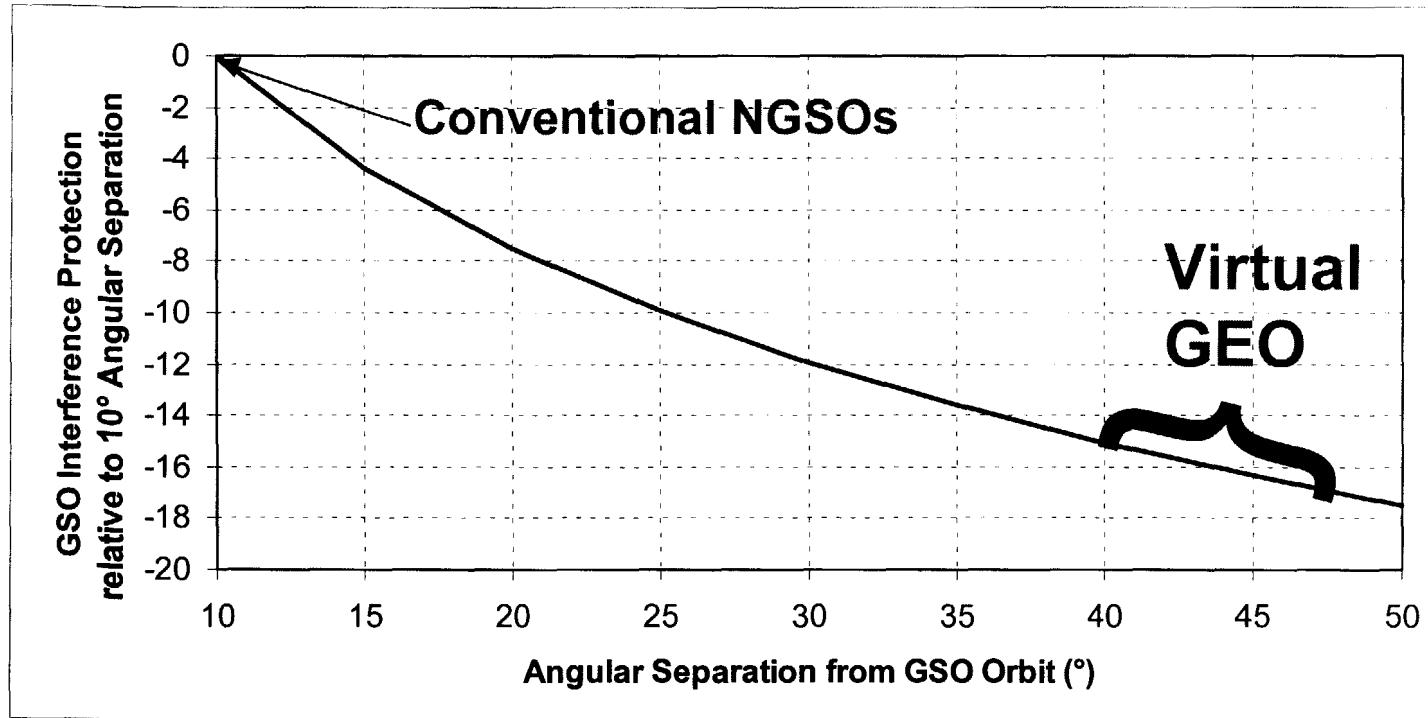


Chart based upon $25\log\Theta$ rolloff

Equivalent to a 40 degree separation on the GSO Arc!

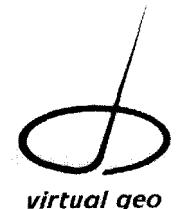
Interference to C-Band GSO Earth Station

Ku Band Similar

Maximum PFD of VIRGO™ satellite in 4 kHz	-165 dBW / m ² / 4kHz
GSO orbit avoidance angle	40°
GSO Rx Earth Station gain towards VIRGO™ satellite	-8.1 dBi
Frequency	4000 MHz
Effective Aperture of GSO Rx Earth Station towards VIRGO™ satellite	-41.5 dB-m ²
GSO Rx Earth Station Interfering Signal Power in 4 kHz	-206.5 dBW / 4kHz
GSO Rx Earth Station Interfering Signal Power Spectral Density	-242.6 dBW / Hz
Increase in interference due to 3 simultaneously visible VIRGO™ satellites	4.8 dB
GSO Rx Earth Station Interfering Signal Power Spectral Density (3 VIRGO™ satellites)	-237.8 dBW / Hz
GSO Rx Earth Station System Noise Temperature	80 K
GSO Rx Earth Station System Noise Power Spectral Density	-209.6 dBW / Hz
I ₀ /N ₀ at GSO Rx Earth Station Input	-28.2 dB

ΔT/T Degradation to Earth Station

0.15%



Interference to C-Band GSO Satellite Receiver

Ku Band Similar

	Clear Sky	Rain	
Maximum PSD into VIRGO™ Earth Station Antenna in 4 kHz	-25.0	-21.8	dBW / 4kHz
GSO orbit avoidance angle	40	40	°
VIRGO™ Tx Earth Station gain towards GSO Satellite	-4.1	-4.1	dBi
VIRGO™ Tx Earth Station EIRP Spectral Density towards GSO Satellite in 4 kHz	-29.1	-25.9	dBW / 4kHz
PFD at the GSO Satellite in 4 kHz	-191.2	-188.0	dBW / m² / 4kHz
Frequency	6325	6325	MHz
Assumed Gain of GSO Satellite Rx towards VIRGO™ Earth Station	40	40	dBi
Effective Aperture of GSO Satellite Rx towards VIRGO™ Earth Station	2.5	2.5	dB-m²
GSO Satellite Rx Interfering Signal Power in 4 kHz	-188.6	-185.4	dBW / 4kHz
GSO Satellite Rx Interfering Signal Power Spectral Density (one VIRGO™ earth station)	-224.7	-221.5	dBW / Hz
GSO Satellite Rx Interfering Signal Power Spectral Density (two VIRGO™ earth stations)	-221.7	-218.5	dBW / Hz
GSO Satellite Rx System Noise Temperature	600	600	K
GSO Satellite Rx System Noise Power Spectral Density	-200.8	-200.8	dBW / Hz
I₀/N₀ at GSO Satellite Rx Input	-20.8	-17.6	dB

ΔT/T Degradation to Satellite Receiver 0.82% (1.7% rain)

Virtual Geo's Relationship to FS

- **VGSO Earth Stations use GEO-type directive, narrow beam Antennas in FS-shared spectrum**
 - Antenna off-axis attenuation adds coordination flexibility
- **VGSO uses high elevation sky-tracks**
 - VGSO accommodates low elevation angle restrictions
- **VGSO satellites follow one sky-track per arc,**
 - Not many, as for other NGSO
 - Permits greater azimuth coordination flexibility relative to NGSO

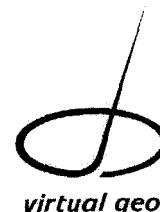
Virtual Geo's Relationship to FS

- **VGSOs offer more slot choices *north and south***
 - More high elevation angle slots are available for the Satcom Industry
- **VGSO satellites are dormant when low**
 - Off axis FS antenna attenuation increases coordination flexibility
 - Possible Exception: Earth-grazing satellite in an opposite region
 - Satellite antenna steering or pattern shaping reduces satellite radiation to earth limbs

Virtual GEO Coverage and Protection to FS

- Coverage optimized over land masses
 - US Coverage Factor*
 - Always > 42 degrees in CONUS 23 dB
 - >30 degrees for VI, PR 19 dB
 - >35 degrees for Hawaii 21 dB
 - Global Coverage: - Elevation Angles
 - Exceed 30 degrees for 50% of land areas 19 dB
 - Exceed 20 degrees for 90% of land areas 15 dB
 - Exceed 10 degrees for 99.9% of coverage area 8 dB
 - Lowest elevation angles occur off land over Atlantic, Indian, and Pacific Oceans

* Relative to 5° minimum elevation angle



NGSO Designs Present Significant Sharing Difficulties

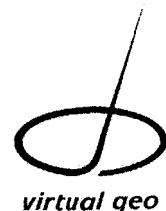
- The GSO arc is a coordinated, agreed-upon orbit
 - Offers visibility advantages — positioning over desired markets
 - Greatly facilitates frequency sharing among many systems
- NGSO systems presently use uncoordinated orbits
 - Frequent crossing interference events
 - More systems add more crossing interference to everyone
 - Limited entry possible
 - Possible requirement for spectrum subdivision — limiting capacity
 - Possible exclusion of future entrants
 - Expensive, non-productive measures necessary to limit effects of crossing interference
 - Diversity — more satellites or ground stations needed
 - Interruptions
 - Limited isolation from GSO

Virtual Geostationary Arcs Overcome “NGSO” Difficulties

- **Virtual Geostationary arcs create new GSO-like opportunities**
 - *Visibility advantages — loitering over desired markets*
 - *Many more systems possible*
 - *50+ Hemispheric, 150+ regional*
 - *No Crossing interference*
 - *Additional interference mitigating resources not required*
 - *More and often better choices for satellite positioning*
 - *No interference to GSO arc or to each other*
 - *Future entry not barred*
 - *Coordination Simplified*
 - *Reuses existing spectrum*

How Do GEO and VGEO Satellites Compare??

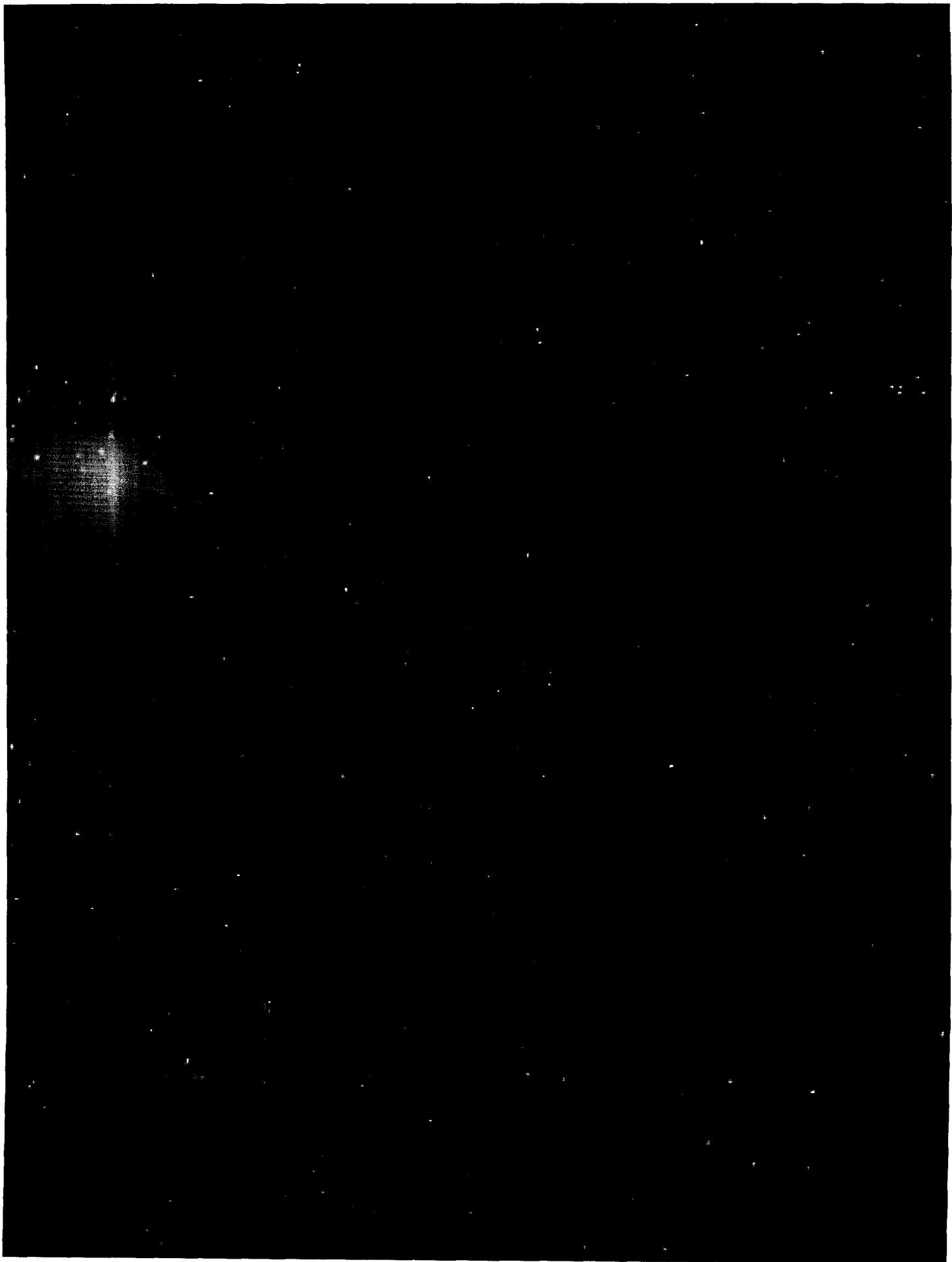
	GEO	VGEO
EIRP (reduced ranges for VGEO)	$P_t G_t$	$0.57 * P_t G_t$
DC Power (lower avg active alt & duty cycle for VGEO)	P_{dc}	$0.51 * P_{dc}$
Satellite Antenna Gains (larger cone angles for VGEO)	G_t	$0.57 * G_t$
Radiation Shielding (more for VGEO)	Standard	Added for payload and arrays
Satellite Antenna Costs (higher for VGEO)	C_a	$2.5 * C_a$
Satellite weight (same performance, w/ shielding)	W_s	$0.62 * W_s$
Satellite Cost, wet	C_s	$0.78 * C_s$
Satellite Launch Costs (reduced wt <i>and</i> ΔV for VGEO)	C_l	$0.37 * C_l$
Per Satellite Cost on Orbit	C_{so}	$0.60 * C_{so}$
Net Constellation Costs (3 sats for GEO; 5 sats (3 active arcs) for VGEO, Hughes GEO equiv)	Same	



The Virtual Geostationary Orbit Standard

- New Operating Vantage Points
- Simple Existing Assignment Rules
- Easier Coordination

Scores, even hundreds of new, interference-free VGSO assignments now possible!



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